JOURNAL OF APPLIED BEHAVIOR ANALYSIS 1992, 25, 43–49 NUMBER 1 (SPRING 1992)

POTENTIAL CONTRIBUTIONS OF PERFORMANCE SCIENCE TO EDUCATION

THOMAS F. GILBERT AND MARILYN B. GILBERT
PERFORMANCE ENGINEERING GROUP

For over 30 years, we have tried to structure and apply a science of human performance, including a technology of instructional design. And although we have performed most of our work in the setting of business and industry, we have also seized every available opportunity to apply this work in schools. The book *Human Competence: Engineering Worthy Performance* (Gilbert, 1978) describes many of the details of what we call performance science.

Is performance science now sufficiently advanced to make a noticeable contribution to education? Yes, it certainly is. By practicing it diligently, we could greatly reduce instructional time (by, say, 80 to 90%), yet at the same time improve its effectiveness. This would leave a lot of time to supplement the usual school curriculum. The problem is not one of technical limitations on getting results, but on how well we can sell the science.

Let's begin with some definitions. What is performance science and how is it different from behavior science? We have been practicing both ever since leaving academia to expose ourselves to the so-called real world. And one of the first things we learned then was the absolute necessity for distinguishing between behavior and performance. The pictorial definition in Figure 1 says it all.

"Performance" is one of those transactional words like "sales." A sale requires both a seller and a buyer; you can't make sense by saying, "I sold him but he didn't buy." "Information" is another such transactional word. It doesn't make sense to say, "I informed them but they didn't understand." Yet we are producing such nonsense every time we confuse information with data. Really we should say, "The data I gave failed to inform them." Similarly, the transactional word "performance" requires that someone do something *and* a result follow. In performance science, the result is the focus of our attention. Accomplishment is a valuable result. In the language of performance science, accomplishment is the dependent variable and behavior is the independent variable. Behavior is the variable we manipulate to see if we can improve accomplishments.

As in most engineering sciences, the dependent variable is our primary economic focus. We are interested in changing behavior only if it will produce a valuable change in accomplishments. It requires money to get people to change their behavior, and the behavior change pays off only when their accomplishments improve. It costs money to improve steel; it pays off when our steel bridges are better.

Although our primary focus is always on accomplishments, it helps to know a lot about behavior to engage in performance engineering. We have found, for example, that a major contributor to poor productivity in the workplace is so-called superstitious behavior, which Skinner once described in the pigeon laboratory. The prime condition for this behavior is accidental reinforcement while working on a variable-ratio (VR) schedule of reinforcement (the ratio of work to reward is high but varies from time to time). Too many sales reps, working under VR conditions, foolishly drop in on key customers without making an appointment, "just in case." Like a draw to an inside straight in poker, these cold calls sometimes pay off, though rarely. Managers, too, remembering rare meetings that did pay off, are forever calling "just-in-case" meetings. In diagnosing and correcting unproductive behavior in industry, we need an understanding

Reprint requests should be addressed to the authors, Performance Engineering Group, RD 3, Box 406, Hampton, New Jersey 08827.

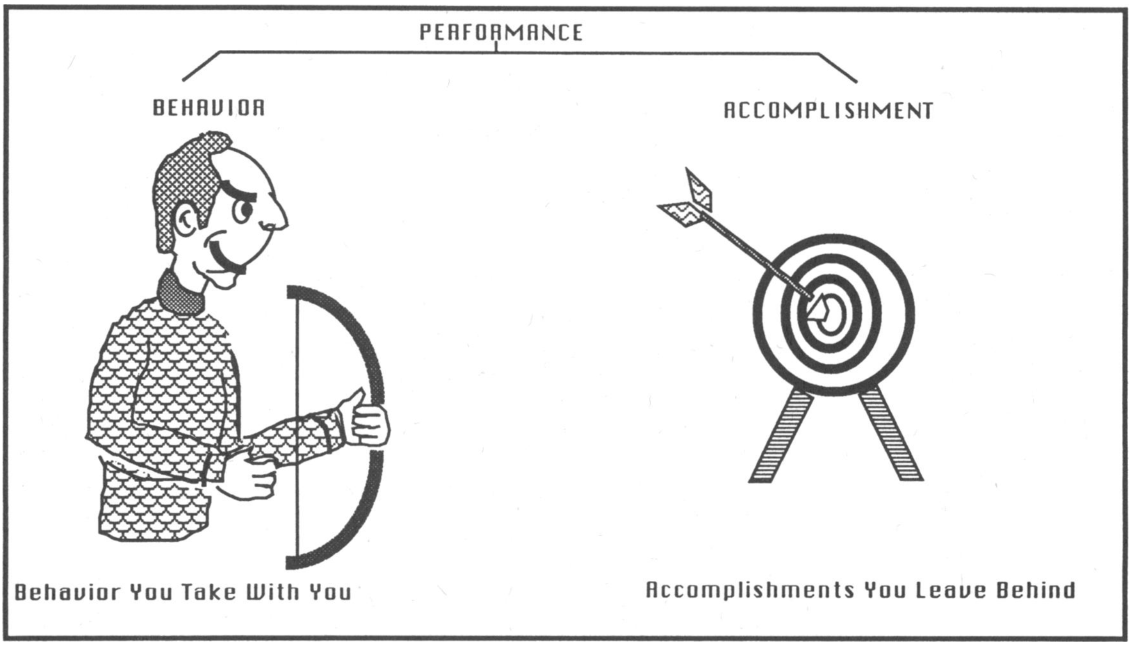

Figure 1. A pictorial definition of performance.

of schedules of reinforcement in order to grasp the principle that infrequent rewards can sometimes be more powerful than frequent ones. It is one of Skinner's strange discoveries that infrequent reinforcement on VR schedules supported higher rates of responding than frequent reinforcement. Ask most people, and they will tell you it should be the other way around.

We have learned how to realize great potential for improving productivity in industry by focusing on accomplishments and studying how changes in behavior can affect them. This same potential exists for improving education in our schools, which, we hear, need help badly. Indeed, we are told that unless we improve productivity in our schools, we won't be able to achieve much more improvement in our industries.

Tactics of Presenting Instruction

So, where are we? Back in the 1950s, B. F. Skinner sent a lot of us off to the educational revolution with teaching machines and programmed instruction. The thinking then was that programming was necessary to break a subject matter down for presentation in small parts, requiring the students to engage actively in the instruction by responding with correct answers and getting instant reinforcement. In reality, though, the teaching machine was just a device for controlling the instruction.

What prompted Skinner's interest in instruction? It was the way we were teaching our students. We were talking to them and rarely requiring them to respond to anything. When we finally got around to requiring them to do something—usually, to take a test—we would delay our feedback for several days or even weeks. Yet experiments in our animal labs had taught us that these procedures were unbelievably inefficient.

Even if the programmed instruction produced back in those days was often of low quality, it still required students to respond frequently, to engage actively in the learning process, and to receive frequent and immediate feedback about how well they were doing. That alone should have been enough to support the programmed instruction movement. But it didn't, although self-instructional workbooks did multiply and some are still in use. Actually, the slow introduction of computers into the classroom heralds the return of the teaching machine.

Table 1
The Relevance of Performance Science to Teaching Multiplication Facts

Customary method	Performance science	Principles
1. Begin with the ones.	Start with the sixes, sevens, and eights.	Teach the hard things first.
2. Then go to the twos, etc.	Teach the sixes, sevens, and eights together simultaneously.	Group the most confusing stimuli together.
3. Have the students go slowly to avoid errors.	Require high speed from the very beginning.	Fluency is mastery and should be required from the beginning.
4. Avoid memory aids for one reason or the other. A common reason we've heard is that they are cheating.	Teach the nines and fives last because they are supported by excellent memory aids.	Memory aids are powerful mediators.
5. Test them once a week, and give them their test scores back a week later.	Let students know their progress instantly as they learn.	Students need to know how well they do at all times.

Tactics for Designing Training

Recently, on a visit to some newly computerized classrooms (first grade through the fourth), we were happy to see the students spending a lot more time responding actively to materials than slumping in their chairs while the teacher talked. But if you do dumb things with the computer, you end up with an elegant system that does dumb things. While observing the teaching of the multiplication facts in the "computerized" third grade, we saw that the feedback was 180° off base. A student was being encouraged by the computer to take his time to get the multiplication answers correct. When the computer showed him the problem 7 × 8 = ____ (framed by a border of cute but distracting pictures), the student twisted mightily in his seat until he finally produced the right answer. Then the computer told him, "Bravo!" So, the computer was reinforcing his getting the right answer, but it was also reinforcing him for getting it in the wrong way. Only high-speed fluency should be reinforced (see Og Lindsley's article on precision teaching in this issue). Otherwise, the student is learning a lot of useless groping behavior that will interfere with retention.

In this interesting example of teaching multiplication facts, not only was the feedback 180° off base, but so was the instructional design. Over the years, we have found about 40 learning principles helpful for designing instruction, although only 8 or 10 may be relevant for any one training problem. The important point is, more often than not, that these learning principles turn 180° in the opposite direction from the customary practices—not just in industrial training departments, but in schools as well. For example, by applying 9 of the 40 or so learning principles of performance science, we can teach kids to master multiplication facts within an hour or two, and they will never forget it. Table 1 illustrates how five of these principles of performance-based instruction apply to the teaching of the multiplication facts and how differently many schools do it.

A brief explanation of a few of our principles is in order. The first of them, "teach the hard things first," applies only to stimulus discrimination training, not to response skills. The hardest things to learn to discriminate here (e.g., sixes, sevens, and eights) only get harder if we learn the easier discriminations first, because the easier things begin to compete with the harder things. This principle we derived from 100-year old studies in the research literature *and* our own verification tests. If the children start with the sixes, sevens, and eights, the task becomes easier as they go. However, if they begin with the twos, threes, and fours, the task of learning becomes progressively more difficult. (The nines are made simple to learn by the use of a memory device, and the fives too.)

The second principle, group the most easily confused stimuli together, is also verified by 100 years of research and validated by our own experiences. This is called "simultaneous" discrimination in the literature, and seems to work well with multiplication facts. Grouping the easily confused stimuli forces students to notice what is different about them. Think about it: Students must learn to make the discriminations sooner or later—the sooner the better.

The teaching of multiplication facts is just one example of using performance science to improve instruction. In many areas, the application of performance science has had even more dramatic results. Almost always, our approaches have been 180° different from the customary efforts. This 180° difference occurs not because educators are dumb, but because they focus on the subject matter that is 180° away from the human head; they are not looking at behavior.

Scientific Strategies for Teaching

There is more to the school problem than simply teaching in dumb ways. A friend of ours, who should know, says that little kids spend a fourth of their math-learning time trying to master mixed fractions, and doing it badly. We can't argue with him because that's about all we can remember studying in arithmetic, except for long division. But Japanese, French, and German students don't learn mixed fractions, and we're told that the British are about to abandon them, too. Why? Because the British, like every one else except us, now use the metric system and decimals (Gilbert & Gilbert, 1992). About the only people who could benefit from the study of mixed fractions in the U.S. are carpenters and tailors who resist using metric rulers—hardly a basis for justifying a quarter of the math-learning time.

Of course, by applying the instructional principles of the new performance science we could devise a quick method for teaching mixed fractions. However, teaching things with great tactical efficiency still isn't right if they are strategically dumb things to teach. We learned this a long time ago, when we designed and developed a national prize-winning course for the Centers for Disease Control. This course reduced the time required to teach people to diagnose amoebiasis (a disease caused by intestinal amoeba) from about 100 hr to about 1 hr. Our students also performed this diagnosis perfectly. But, alas, we learned afterwards that there was no amoebiasis in the U.S., and the CDC really had no business studying it. The Indian government certainly has an interest. Those people squatting on the banks of the Ganges are not lazy louts—they have amoebiasis. Unfortunately, our course was never translated into the Hindu language.

Performance science rises to its best when confronted with strategic issues of teaching. Here, it requires us to focus sharply on accomplishments, and on those accomplishments we value. Without a performance science to guide us, this is unusually difficult for human beings to do. This is because, for the brief 2,500 centuries our species has existed, we have had little to do except observe human behavior. We have become very good at it. From a distance of a couple of hundred feet, the great turn-of-the-century French actress, Sarah Bernhardt, could make even her back-row audience break into tears as she lifted her eyebrow just a fraction of a centimeter. However, over those few centuries, we have had few accomplishments to observe—just a small collection of things like bringing home the berries and making clay pots. Only in the 20th century have these accomplishments in the world of work grown terribly complex and difficult to describe. We now really need a performance science to guide us in doing this well. When we ask our clients in industry to describe accomplishments, they immediately look to behavior. It's a 2,500-century-old habit. The hardest thing we have to do is teach them how to describe accomplishments, although our memory aid helps: Behavior you take with you; accomplishments you leave behind.

If we begin with the notion that education, like training, should produce valuable accomplishments, we will quickly toss out mixed fractions and also a great deal of our methods for teaching history. Methods of teaching history are a particularly good example of how performance science can tackle the strategic issues of instruction.

Saying What A Subject Matter Is

How do we now decide on our history curriculum (Gilbert, 1976)? By letting a bunch of experts make a list of things to be learned, like the dates of Queen Anne's War and the War of the Roses. That's about all we remember being taught; we haven't the faintest idea what these wars were all about, partly because our history tests never asked.

How would we decide on a history curriculum if we applied performance science? Performance science begins with a rather precise way of sorting out and deciding which accomplishments are really valued. One of the first things the science leads us to do is to identify various alternative accomplishments we might find valuable. This is not all that easy to do in an industrial organization, where it is fairly easy to discern who is in charge. It is even more difficult in our school systems, where it can be debatable who the responsible decision makers are. We begin with the assumption that it is the public who is ultimately in charge, because ultimately the public pays for the instruction.

With this as our lead, we begin searching for history mastery models that the public might value. What do we want our students to be able to accomplish as a result of learning history? Here are four possible models:

1. We could define history performance as a written record of past events, and then select an *archivist* as our mastery model—one able to maintain a written record of the past. Students could become library scholars and teachers.

2. Or we could define mastery of history as what certain kinds of *raconteurs* do—relate and interpret the events of the past. Students could become journalists, propagandists, essayists, or historical novelists.

3. We could, indeed, even define history as what *history makers* do, and train our kids to become warriors, politicians, philosophers, and playwrights.

4. We can think of only one more mastery model—the *explainers* and *predictors,* who deduce the variables that make it easier to account for events, then forecast the direction they might take and perhaps even visualize how the course of events could be altered.

Some years ago, we conducted a rather informal experiment in which we asked about 100 people, most of them parents, which of these accomplishments they most valued. Their responses were as follows:

1. Most thought that raconteurs and archivists represented valuable vocations, but not for many people to elect. So, they rejected these as a guiding model. Almost all seemed to think that these were the models driving our school curricula, however.

2. Our respondents didn't make much of history makers as a model for a curriculum. One even commented that most of these people were trouble makers, and that we shouldn't go out of our way to create too many more of them.

3. Very close to 100% of our respondents elected the fourth model of mastery: being able to identify the important variables that accounted for past events and paved the way for future events.

Having decided what mission our respondents wanted children to achieve—explainers and predictors—we next made a list of key accomplishments that would get our students to master this ultimate mission. Then we took several sets of events in history on which to apply our model and test it. For one of these events we chose something called the Cargo Cult. Very briefly, this Cargo Cult refers to the peculiar behavior patterns that developed among several primitive Pacific tribes when allied World War II aircraft misdirected their supply drops, and the natives for the first time saw "manna from heaven." What happened, of course, was that these tribes began to engage in all sorts of destructive behavior directed by their superstitions—like banging drums and worshipping the sky rather than hunting.

Below is a list of key accomplishments that would teach our students to become explainers and predictors of history, and how these accomplishments could be applied to teaching the Cargo Cult:

Step 1. Read or hear a story rich in details. For the Cargo Cult, these were strange events, interacting in all sorts of ways.

Step 2. Identify the "big" variables that could shape the events of the Cargo Cult.

Step 3. Identify two or three of these big variables that most accounted for the events peculiar to the Cult. They were (a) a change in the resources of the tribes and (b) the instrumentalities of seeking a living.

Step 4. Restate the question in a more abstract form. How do accidental resource contingencies affect the instrumentalities for seeking a living that have been paying off on a variable-ratio schedule?

Step 5. Search for any laws, rules, or other experiences that would help answer the restated question. Here is an explanation: Accidental resource contingencies occurring under a variable-ratio schedule of seeking food are ideal for establishing superstitious behavior. In a primitive tribe, this could be very destructive and would require planned intervention to protect the people.

Space does not permit us to unfold further details of a performance-based curriculum, but obviously it bears little resemblance to the way our history curricula are usually developed. These examples of tactics and strategies of instruction do not nearly describe all the ways a performance science approaches instruction, but they should illustrate some of its power. We think it is inevitable that performance science, sooner or later, will begin to shape the way we conduct education in the schools. Yet now, this very day, 98% of our children could begin to achieve the following results and achieve them to the highest standards of performance if we applied performance science to education—and these are only a few examples:

1. All the mechanics of math (including algebra and plane and analytic geometry) could be accomplished by the end of the third grade.
2. Use of math to solve problems of reasoning: substantial progress by the third grade and superior skills by the sixth grade.
3. Mastery to high standards of English pronunciation, grammar, spelling, reading, and writing by the fourth grade.
4. Fluent mastery of a second language by the sixth grade.
5. By the fifth grade, reasoning through issues representing several social sciences by a model like the one we described above for history.
6. Mastery of the several main processes of science by the eighth grade.
7. By the third grade, mastery of the ability to design memory aids for learning. This, like the next accomplishment, would be taught to improve the students' ability to teach themselves.
8. By the third grade, mastery of Robinson's SQ3R method of studying (Robinson, 1946).

We have the technical know-how to teach children to these standards now. But to achieve anything, we must learn to ignore those who doubt our ability. One psychologist snarled and said we wanted to teach children to bark the multiplication table like dogs. And he was exactly right. We do want children to bark the multiplication table without pausing to think. On the other hand, we also want children to pause and think their way through history. Right now, our schools have it just the other way: Our kids learn to think their way through multiplication facts, as they learn to bark out historical dates. What we will need to make all this possible is a way to sell the science, and that isn't easy. Perhaps, though, help is buried in the performance science itself.

Performance Science at the Policy Levels

One of the great powers of performance science is its economic models of performance. (All successful engineering sciences must come to grips with the economics of what they are doing.) One of these models accounts for the costs and values of training. Industry is just now beginning to give serious attention to measuring and reporting the true costs of industrial training, which is 10 times greater than people think it is. Ninety percent of this cost appears in no one's budget, and that is the cost of the loaded wages we pay employees to learn their jobs. Nationwide, this cost exceeds our annual defense budget.

Similarly, the numbers in the economics of schools are very large indeed, and especially the economic consequences of kids ***not*** learning. Unfortunately, no one is going to pay serious attention to improving instruction until people appreciate its true economics and respond to it as real opportunity to make the nation more productive. Yet, in point of fact, we could construct an economic model for the schools right now, and begin to let people see what the cost really is. Perhaps, then, our client—the public—would take performance science seriously when shown blatant evidence that the investment really has something in it for them.

REFERENCES

Gilbert, T. F. (1976). Saying what a subject matter is. *Instructional Science,* **5,** 29–53.

Gilbert, T. F. (1978). *Human competence: Engineering worthy performance.* New York: McGraw-Hill.

Gilbert, T. F., & Gilbert, M. B. (1992). *Mastering metrics in minutes.* Amherst, MA: HRD Press.

Robinson, F. P. (1946). *Effective study.* New York: Harper & Brothers.

Received December 10, 1991
Final acceptance December 15, 1991
Action Editor, E. Scott Geller